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DETERMINING CRITICAL DEPTH OF WATERWAYS, CANALS

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In conducting hydraulic calculations for waterways and canals and for hydraulic engineering projects, it is generally difficult to find the critical depth.

As we know, the critical depth in a waterway of any form, relative to the flow cross section, is the depth corresponding to the kinetic forces of the flow, characterized by Froude's number F = 1; i.e.

$$\frac{\alpha Q^2}{g} \cdot \frac{B_k}{\omega_k^3} = 1, \text{ or } \frac{\alpha Q^2}{g} = \frac{\omega_k^3}{B_k}$$

where ω_k is the area of the kinetic section at depth equal to the critical; B_k is the compass width at the same depth.

Since we may always write $\omega_k = a_1 h_k^2$ and $B_k = a_2 h_k$, the general expression for the critical depth in a waterway of any form is obtained from the equation

$$\frac{\omega_k}{B_k} = \frac{a_1^3}{a_2} h_k^5 = A h_k,$$

or

$$\frac{\alpha Q^2}{g} = A h_k^5$$

or

$$h_k = \sqrt[5]{\frac{1}{A} \frac{\alpha Q^2}{g}} \qquad (1)$$

This general expression for critical depth with any cross-section may be converted easily for various individual forms.

For a trapezoidal form, considering that $\beta = \frac{b}{h}$, we have $a_1 = \beta_k + m$; $a_2 = \beta_k + 2m$; and therefore

$$\left[A = \frac{(\beta_k + m)^3}{\beta_k + 2m}\right. \qquad (2)$$

$$h_k = \sqrt[5]{\frac{\alpha Q^2}{g} \cdot \frac{\beta_k + 2m}{(\beta_k + m)^3}}.$$

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It is immediately obvious that, in the particular case where b = 0, and β = 0, i.e., with a triangular profile, we have $h_k = \sqrt[5]{\frac{2\alpha Q^2}{g m^2}}$, or when α = 1

$$h_k \cong 0.73\sqrt[5]{\left(\frac{Q}{m}\right)^2} \qquad (3)$$

(Note that in some hydraulics courses, the coefficient in this formula is erroneously given as 0.29).

In the particular case where m = 0, i.e., for a rectangular profile, we have

$$h_k = \sqrt[5]{\frac{\alpha Q^2}{g \beta_k^2}} = \sqrt[5]{\frac{\alpha Q^2}{g} \cdot \frac{h_k^2}{b^2}}$$

or, considering that $q = \frac{Q}{b}$, and solving for h_k, we find $h_k = \sqrt[3]{\frac{\alpha q^2}{g}}$; if α = 1, we obtain the recognized formula

$$h_k = 0.467 q^{\frac{2}{3}} \qquad (4)$$

In all cases where b > 0 and m > 0, the critical depth will be found according to formula (2). Obviously, accurate solution directly by this formula is made difficult since not knowing h_k, we do not know β_k, which necessitates solving (2) by selection. However for the majority of broad waterways, it is possible to simplify selection. Formula (2) gives a sufficiently accurate, though approximate solution if β_k is assumed equal to $\frac{b}{h_k}$, substituting, in place of the actual (for a trapezoidal section) critical depth, a depth corresponding to a rectangular section, with a width on bottom equal to the width of a given trapezoidal waterway.

In such a case

$$\beta_k = \frac{b}{0.467 q^{\frac{2}{3}}} = 2.15\, b \sqrt[3]{\left(\frac{b}{Q}\right)^2}. \qquad (5)$$

Computed by this formula, β_k obviously will always be less than β_k for a trapezoidal section.

Substituting this quantity for β_k in formula (2), we find h'_k and check whether $\beta'_k = \frac{b}{h'_k}$ will actually be close to the quantity given in (5).

In case of discrepancy (for narrower waterways with flat slopes), we must substitute in (2) a new value of $\beta'_k = \frac{b}{h'_k}$, where it will be necessary to take h'_k according to the estimate obtained, and again check the quantity β''_k. It is usually possible to end solution of the problem at this point without further substitutions.

Such a solution eliminates the use of more complex formulas [1] or the use of tables [2] and graphs [3].

We propose the following table of values for a_1, a_2, and A, and also "working" formulas for determining critical depth of profiles of varied form.

Form	[illegible]	a	A	Working Formula when $\alpha = 1$
1. Triangular, symmetrical	m	$2m$	$\frac{m^2}{2}$	$h_1 = 0.$[illegible]$\sqrt{\left(\frac{Q}{m}\right)^2}$
2. Triangular, nonsymmetrical	$\frac{m_1 + m_2}{2}$	$m_1 + m_2$	$\frac{(m_1 + m_2)^2}{8}$	$h_k = \sqrt[5]{\frac{8\alpha}{g}\left(\frac{Q}{m_1 + m_2}\right)^2}$
3. Rectangular	β_k	β_k	β_k^2	$h_k = 0.467 q^{\frac{2}{3}}$
4. Parabolic $\omega = \frac{2}{3} B \cdot h$ $\left(\frac{B}{2}\right)^2 = 2ph$	$\frac{2}{3}\sqrt{\frac{8p}{h_k}}$	$\sqrt{\frac{8p}{h_k}}$	$\left(\frac{2}{3}\right)^3 \frac{8p}{h_k}$	$h_k = 0.455\sqrt[4]{\frac{Q^2}{P}}$
5. Trapezoidal	$\beta_k + m$	$\beta_k + 2m$	$\frac{(\beta_k + m)^3}{\beta_k + 2m}$	$h_k = 0.63\sqrt[5]{\frac{(\beta_k + 2m) Q^2}{(\beta_k + m)^3}}$
A. V. Troitskiy's formula		$h_k = \sqrt[x]{\frac{\alpha Q^2}{g} \cdot \frac{\text{[illegible]} + 2m}{(b+m)^3}}$		

(In the last formula, the index of the degree $x = 3\frac{\beta + 2m}{\beta + m} - \frac{2m}{\beta + 2m}$, and is called by Troitskiy "the hydraulic index of the section," as distinct from B. A. Bakhmetev's hydraulic index of the waterway.)

REFERENCES

[1] Cf Troitskiy's formula in table.

[2] Cf Prof I. I. Agroskin's tables in the book "The Hydraulics of Canals," 1940.

[3] Cf Prof A. N. Rakhmanov's graphs in Prof K. L. Chertousov's "Special Course in Hydraulics," 1937; also graphs by A. M. Latyshenkov (Gidrotekhnicheskoye Stroitel'stvo, No 2, 1947); A. A. Uginchus (ibid., No 8, 1947); P. G. Kiselev, (ibid., No 11, 1948).

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